Session Outline – Purposeful Data Collection

2:00 – 2:30

- **CAC Spectrum Monitoring – Progress in Purposeful Data Collection**
- Cotton (NTIA/ITS), Ranga (NIST/CTL)

2:30 – 3:00

- **A Spectrum Environment Awareness System – Monitoring and Data Analytics for Spectrum Management**
- Gemme (SITT/ISED), Li (CRC)

3:00 – 3:15 Break

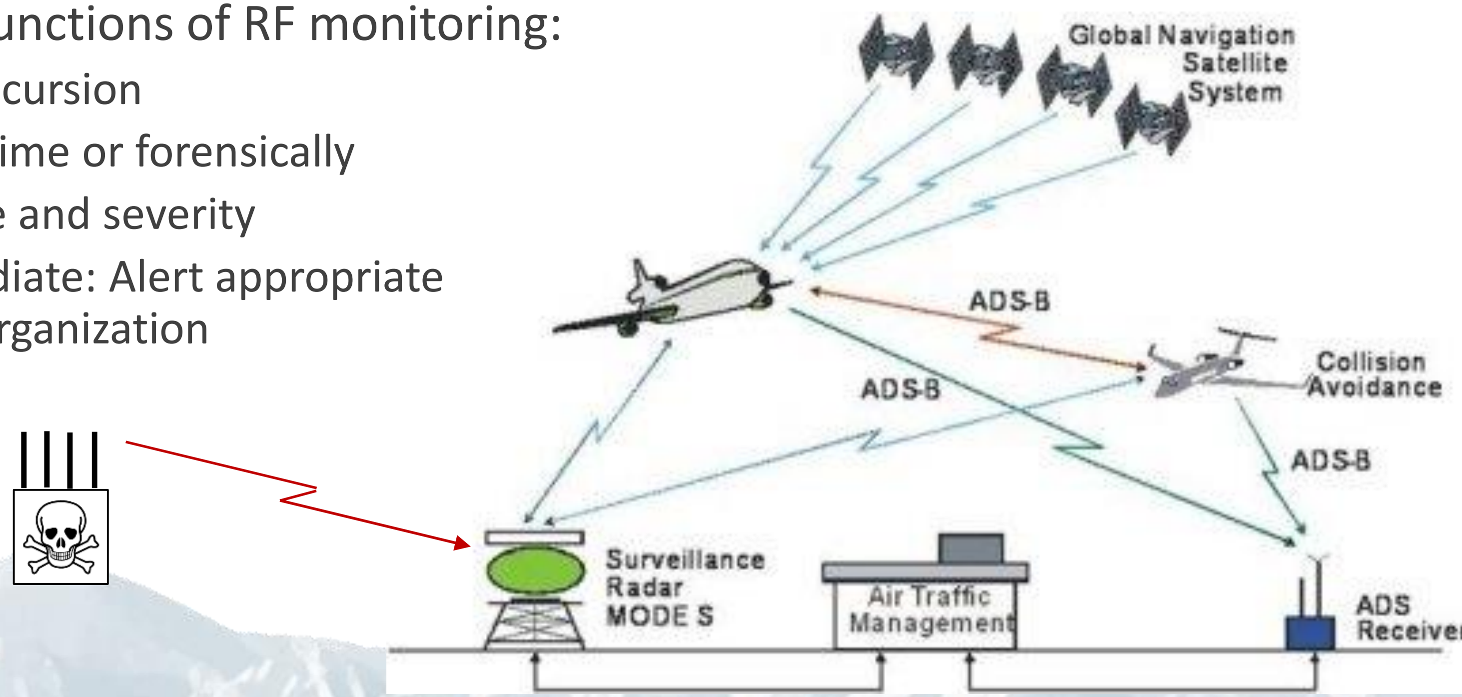
3:15 – 5:15

Spectrum Monitoring Panel

- Goal: To discuss and develop systems architectural requirements in monitoring to support spectrum enforcement/forensics
- Themes:
  - **Systems Architecture**
  - Use Cases
  - Interfaces
  - User Requirements
  - Roles , Areas of Specialization
  - Public Benefit
- Things to Look For:
  - Distributed v Centralized Architectures
  - General v Specific Requirements
  - Regulatory v Agency v Industry v Academic Perspective
  - International Context and Solutions

A Need: Support Enforcement

- Some systems that could be affected by interference are mission/life critical, e.g., radars, public safety comm, military training and telemetry, satellite comm, medical
- Need a cost-effective means to effectively monitor the “RF perimeter” of an “RF reservation” (i.e., protected region bounded in space, time, and frequency)
- Enforcement Functions of RF monitoring:
  - Detect an RF incursion
  - Locate in real-time or forensically
  - Classify by type and severity
  - Resolve/Remediate: Alert appropriate enforcement organization



Another Need: Spectrum Management needs to be Proactive/Automated instead of Reactive/Static

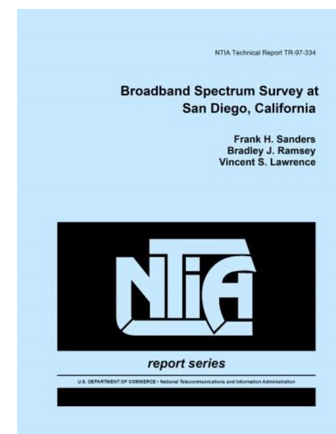
- Characterize baseline in absence of incumbent, e.g., MMN, adjacent band emissions
- Measure incumbent use of the band
- Improve models to predict behavior – e.g., MMN, occupancy, site-specific propagation effects
- Recognize change and trends
- Real-time visualization and signal/whitespace mapping
- Detect potential interference events and notify
- Verify that a radio systems behave as intended
- **Forensics - Build evidence for adjudication**
- Support ex post rule adaption

The Work to be Done: Develop Architecture

- To perform RF perimeter monitoring that is economical, efficient, reliable, effective, and secure
- To facilitate collective actions and enable widespread data collection to modernize spectrum management/ enforcement (in general) and fully exploit the spectrum resource.

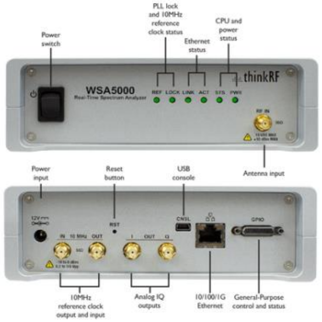
Why isn’t it done?

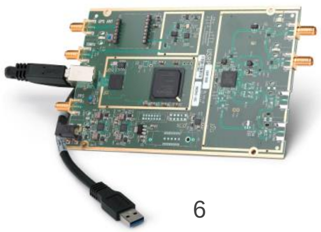
- In past, spectrum measurements required expensive equipment
- Common standards and metadata requirements were not developed and used broadly to promote data aggregation
- No infrastructure to pull all this together



Why Now?

- Sensors are cheap and plentiful
- Ubiquitous computing and networking
- DOC has an initiative to share data and promote collaboration and open-source solutions
- CAC Spectrum Monitoring Program is implementing a proof of concept system to evaluate and develop monitoring and enforcement technology



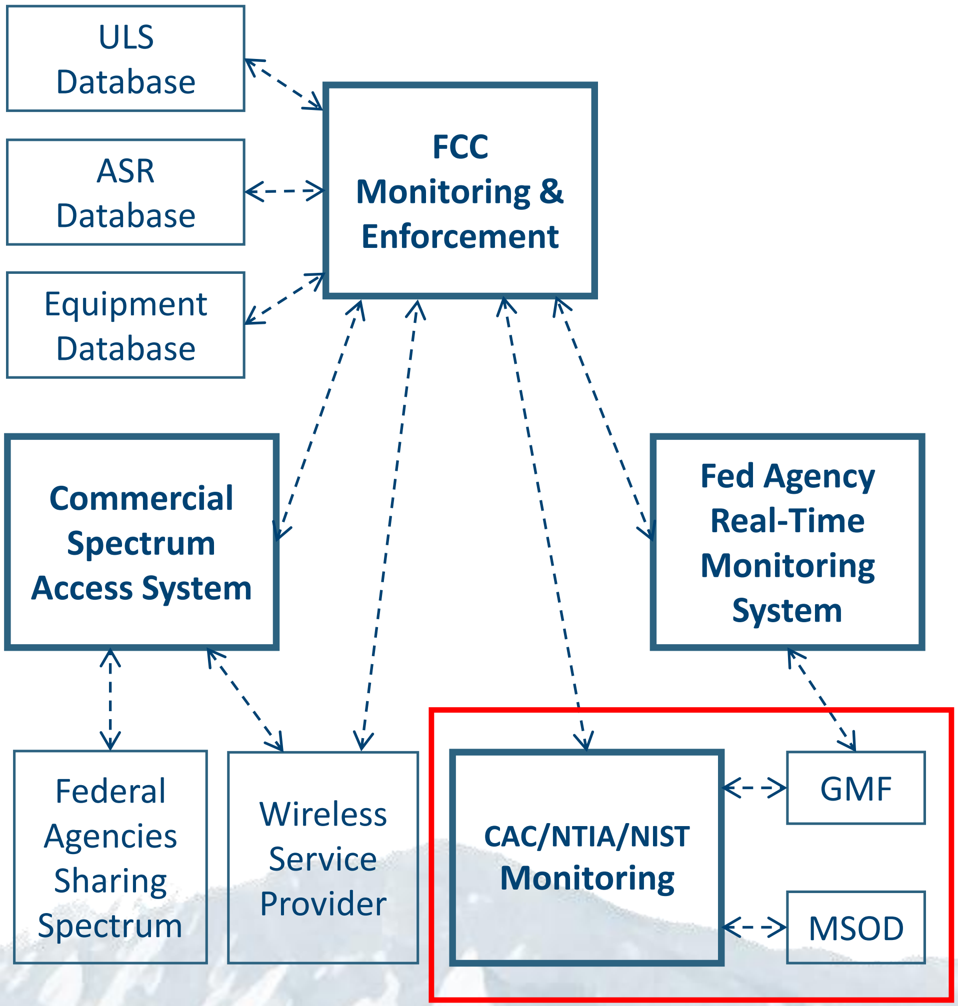


Challenges

- **Business model:** It is expensive to maintain a continuously operating data collection network, especially with expanding scope
- **Recruitment:** Will there be buy-in?
- **Specialization:** Different domains of expertise are required
- **Sensor Technologies:** Appropriate sensor quality, mix, number, antenna, detection, deployment strategy can be difficult to determine
- **Data Diversity:** Disparate data sources, types, methods of acquisition
- **Data Quality:** Objective measures on data quality are needed to determine usability for different purposes
- **Cybersecurity:** Cybersecurity policies to protect private and sensitive data
- **Spectrum Monitoring Still in R&D:** Spectrum management will not utilize spectrum monitoring until it moves from R&D to production.

Approach (1)

- Make it Easy to Contribute
  - Open Source Architecture that Supports the Evolution of Ubiquitous Spectrum Monitoring
  - Metadata requirements that enable aggregation, analytics, and data quality measures
  - Standardized interfaces that enable modular/scalable solutions, specialization, economies of scale
- Make it Real
  - Spectrum Management Policies to Leverage Monitoring
  - Protect, Detect, Respond, Recover
  - Contribute evidence to an enforcement or judiciary process



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Approach (2): Blow up

Data Sources

Integration/Fusion of Data from Different Sources

- Forensic Data
- Performance Metrics
- Occupancy
- Energy
- Interference Events

Analysis and Forensic Tools

Spectrum Management:

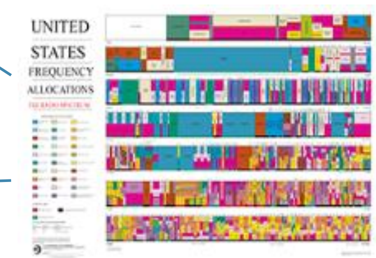
Protect, Detect, Respond, Recover

Enforcement:

Detect, Locate

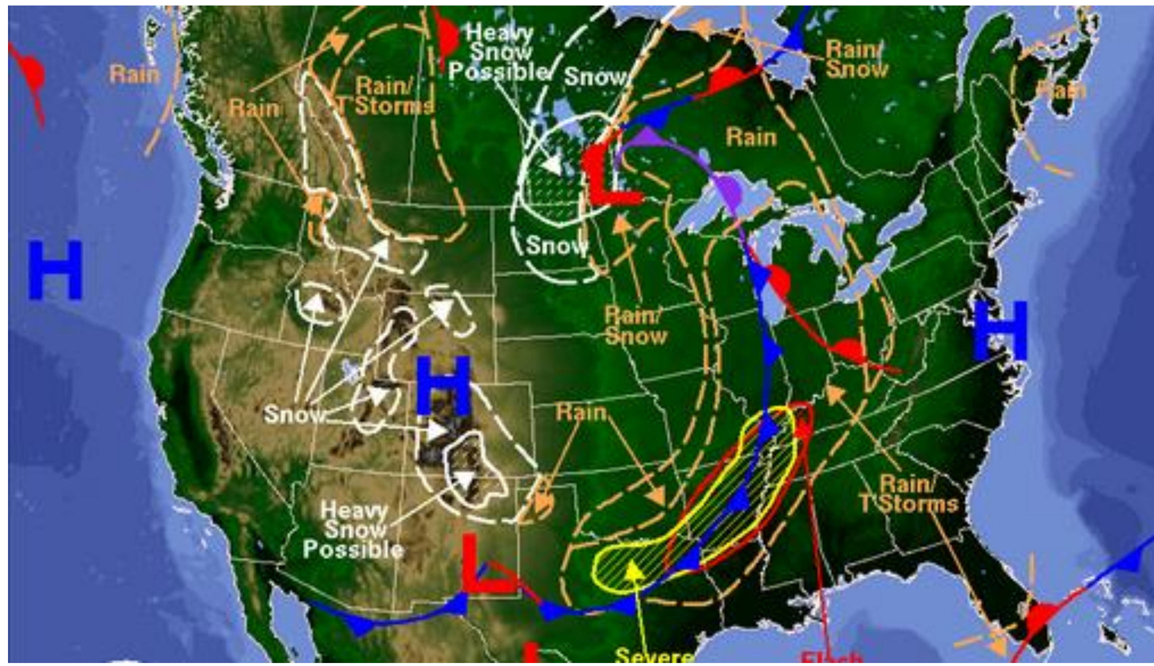
Classify/Identify, Resolve, Remediate

License and Assignments



Vision: Embedded and Pervasive Enforcement

- RF enforcement map or dashboard analogous to NOAA weather map making predictions from field of sensors to avoid community loss
- U.S. Government and commercial sector can detect and respond to any breach of spectrum sharing agreements
- U.S. Government has means to detect and respond to attacks on RF infrastructure



Center for Advanced Communications

CAC Spectrum Monitoring
Progress in Purposeful Data Collection

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Presented at ISART 2016, Boulder, CO, August 2, 2016

Institute for Telecommunication Sciences
Boulder, Colorado

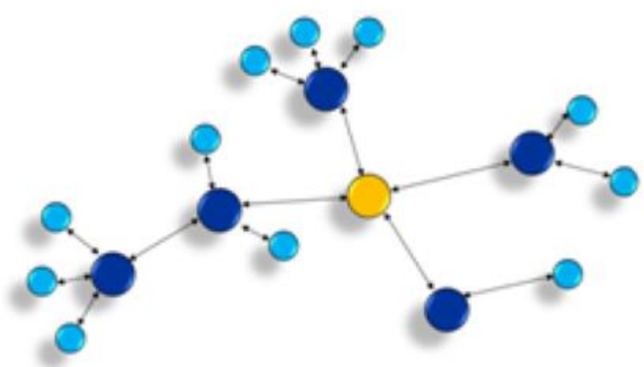
Communications Technology Laboratory

CAC Spectrum Monitoring - Outline

- Goals
- Measured Spectrum Occupancy Database (MSOD)
  - How Can You Contribute?
  - High-Level Architecture and Server Requirements
  - Services and Interfaces
  - Screen Captures
- Sensor
  - Control and Algorithmic Flexibility
  - Forensic Metadata (When, Where) and Data Aggregation
  - Forensic LTE DownLink Identification (Who, What)
  - Prototypes
  - SDR Testing and Calibration
- Boulder Wireless Test Bed

CAC Spectrum Monitoring Goals

- Develop architecture to amass spectrum monitoring data and make it available to the community in near real-time via the Internet
- Establish best practices for acquisition and management of spectrum data
- Maintain a small network of operating nodes in a priority sensing scenario
- Enable outside contributions of data, hosted databases, software, firmware, sensor designs



How Can You Contribute?

NIST AWS MSOD*: https://spectrum.nist.gov/spectrumbrowser

- Host your own MSOD
  - Run our public Amazon Machine Image
  - Run on your own hardware
  - Federate with peer organizations
- MSOD code repository
  - https://github.com/usnistgov/spectrumbrowser
  - Build and deploy instructions
  - Data transfer specification
- Send data to NIST AWS MSOD
- Sensor registration – send email to Ranga with the following info:
  - Example set of messages from sensor to test for compatibility
  - Your Organization
  - Synopsis (use-case)
- Coming soon: NTIA and NIST sensor code repositories

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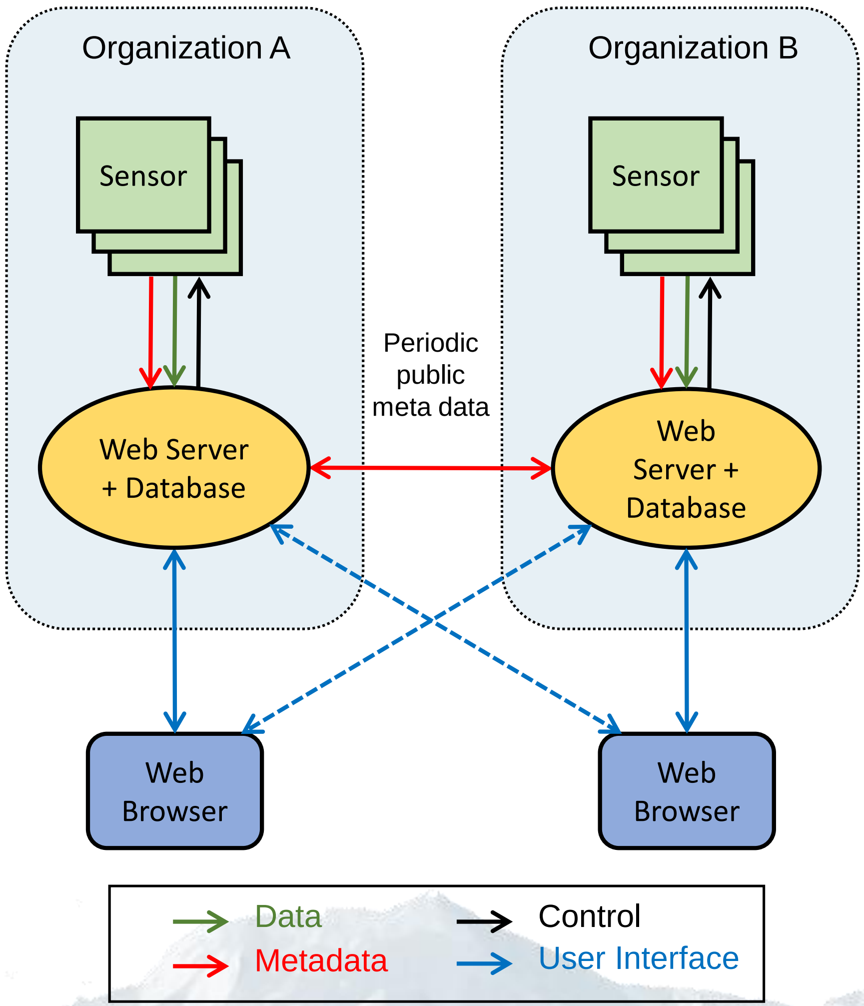
*MSOD = Measured Spectrum Occupancy Database

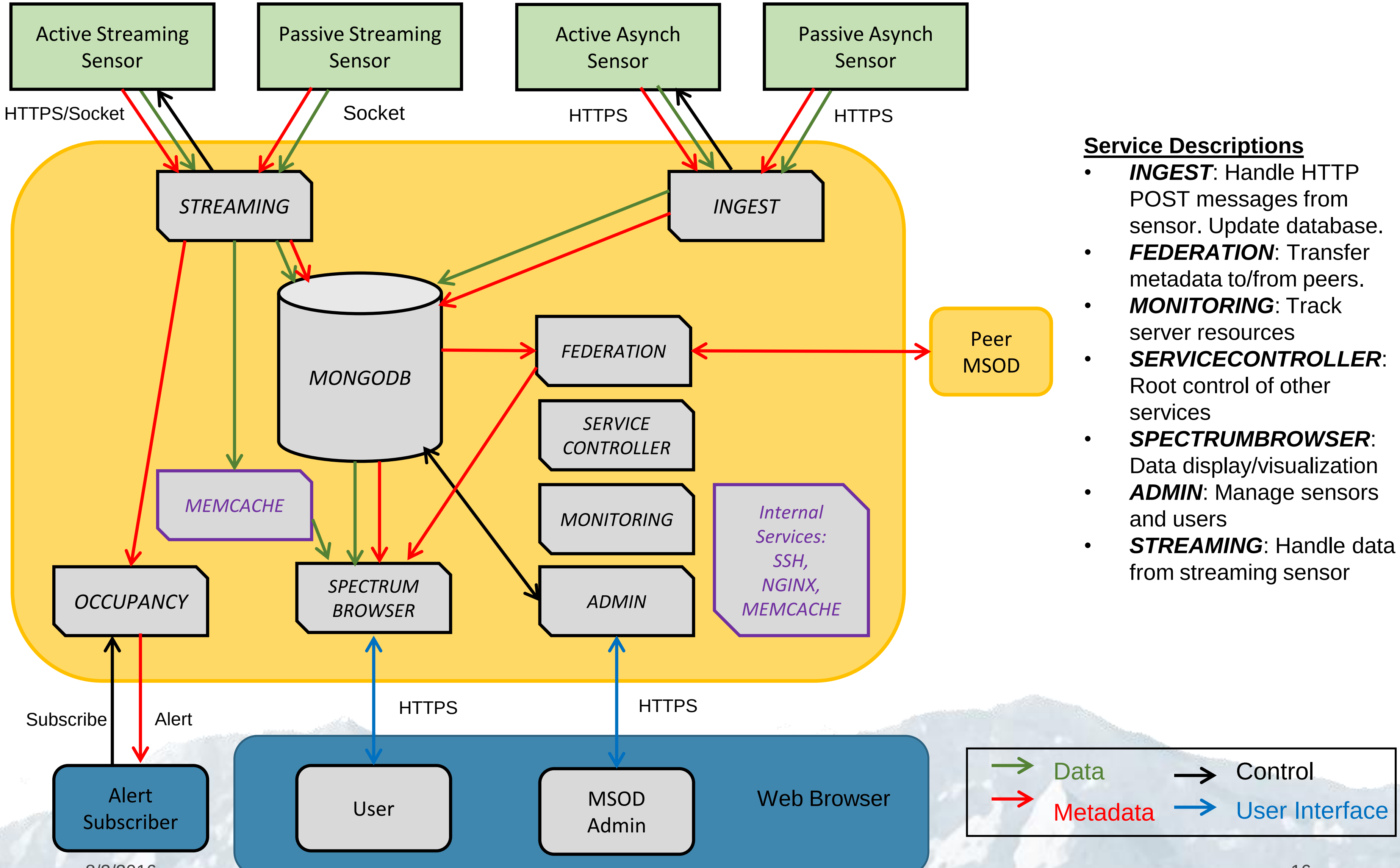
High-Level Architecture and Requirements



- Distributed MSOD* architecture enabling organizations to host and share data with peers
- Continuous acquisition and management of calibrated power spectra data measurements
- Web-based sensor/user access and authentication
- Active sensor control or passive data ingest
- Data aggregation from disparate types and grades of sensors
- Geographic sensor presentation
- Calculation of long-term occupancy trends and short-term spectrograms
- Real-time event notifications via publish-subscribe
- Triggered IQ sampling with variety of detection/decode algorithms at sensor
- Administration page with server and sensor operations
- Open source

*MSOD = Measured Spectrum Occupancy Database

MSOD Services and Interfaces



Service Descriptions

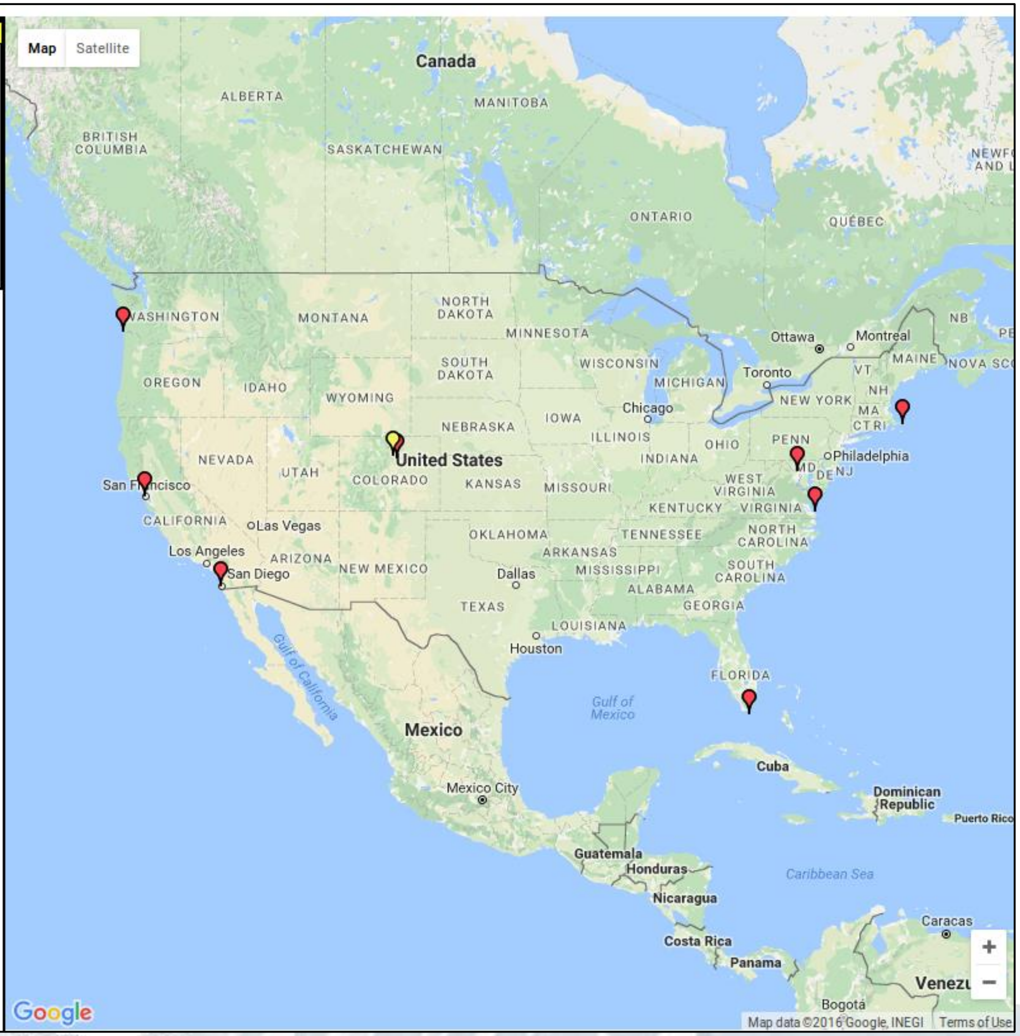
- ***INGEST***: Handle HTTP POST messages from sensor. Update database.
- ***FEDERATION***: Transfer metadata to/from peers.
- ***MONITORING***: Track server resources
- ***SERVICECONTROLLER***: Root control of other services
- ***SPECTRUMBROWSER***: Data display/visualization
- ***ADMIN***: Manage sensors and users
- ***STREAMING***: Handle data from streaming sensor

MSOD Screen Capture: Available Sensors

Sensor Information Display

Sensor ID = NTIACommSensor-1
Sensor Model = Ettus USRP B210
Location: Lat = 39.99; Long = -105.26; Alt = 5423.00 Ft.
Antenna Type = Unknown (whip)
Measurement Type = FFT-Power
Data Start Time = 2016-07-29 12:52:11 MDT
Data End Time = 2016-07-29 14:46:11 MDT
Aquisition Count = 39

Frequency Bands (Click to select below):
LTE 745.96 MHz - 756.04 MHz

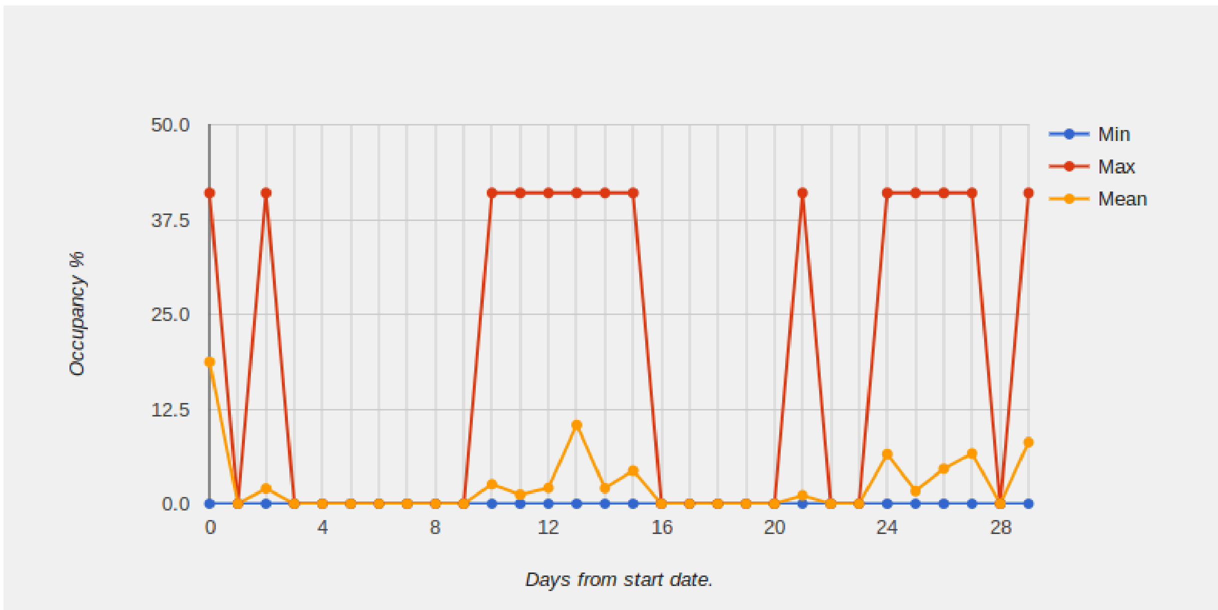


MSOD Screen Capture: Daily Occupancy

Start Date= 2015-08-01 00:00:00 PDT;Detected System = Radar-SPN43; minFreq = 3649.5 MHz; maxFreq = 3550.5 MHz; channelCount = 100; Occupancy Threshold = -90 dBm

Click on a point to see detail.

Next 30 Days >>



MSOD Screen Capture: Single-Day Spectrogram

Detected System = Radar-SPN43; Start Time = 2015-08-19 00:00:00 PDT; Occupancy Threshold = -90 dBm; minPower = -92 dBm; maxPower = -12 dBm

Aquisition Count = 1440; max occupancy = 60%; min occupancy = 0%; mean occupancy = 2.4%; median occupancy = 0%

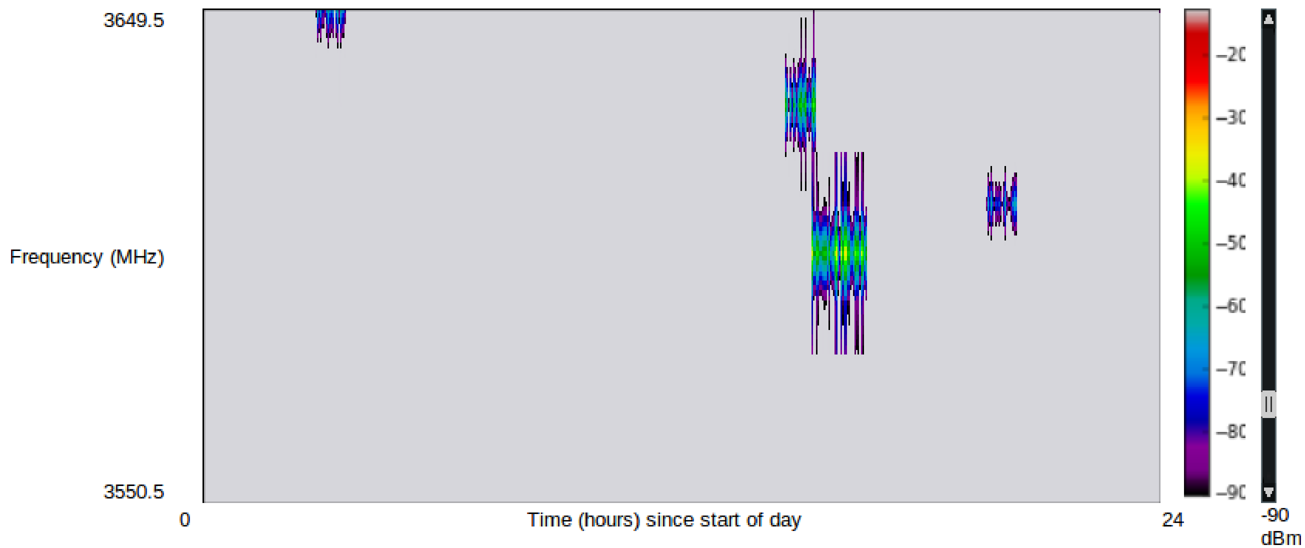
Equiv. Noise BW = 1128000 Hz; Resolution BW = 1000000 Hz.

Click on spectrogram or occupancy plot for detail. Move slider and and click on redraw button to change threshold and redraw.

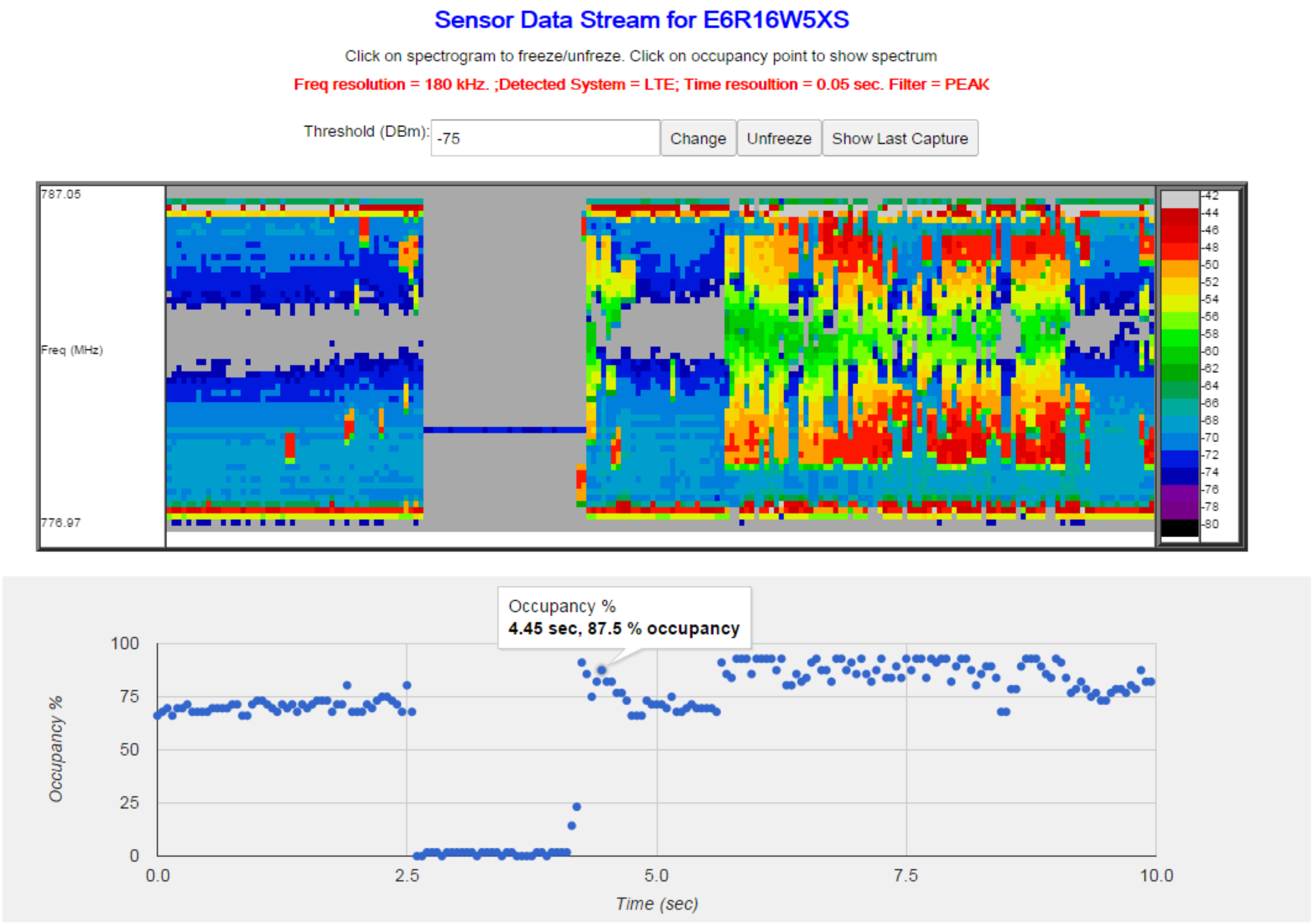
< Previous Day | Cutoff and Redraw | Close Tabs | Next Day >

[Spectrogram] [Occupancy]

Click on spectrogram for power spectrum at selected time.



MSOD Screen Capture: Real-Time Data Stream



MSOD Screen Capture: Sensor Administration

CAC Measured Spectrum Occupancy Database Administrator Interface (BETA)

System Config | Screen Config | Outbound Peers | Inbound Peers | **Sensors** | User Accounts | Sensing Agents | Sessions | System Monitor | Debugging Logs | Service Control

Configured sensors.

Select Add button to add a new sensor. Buttons on each sensor row allow you to reconfigure the sensor.

Sensor Identity	Storage Management	Frequency Bands	Show Activity	Enabled?	Get System Messages	Streaming and I/Q Capture	Startup Params	Duplicate Settings	Purge Data	Remove Sensor	Configuration Status	Run Status
SensorSim1	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
RadarSensorSim1	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
RadarSensorSim2	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
NTIACommSensor-1	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
RadarSensorSim3	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
RadarSensorSim5	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
rtl-sdr1	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
nist-rtl-sdr	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
RadarSensorSim4	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
RadarSensorSim6	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
NistUsrpSensor1	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED
isart-demo-rtl	Manage Storage	Change/Add	Show	☑	Get	Set/Change	NONE	Dup	Purge Data	Remove Sensor	Configured	ENABLED

Add new sensor | Refresh | Log Off

Forensic Metadata (When, Where) and Data Aggregation

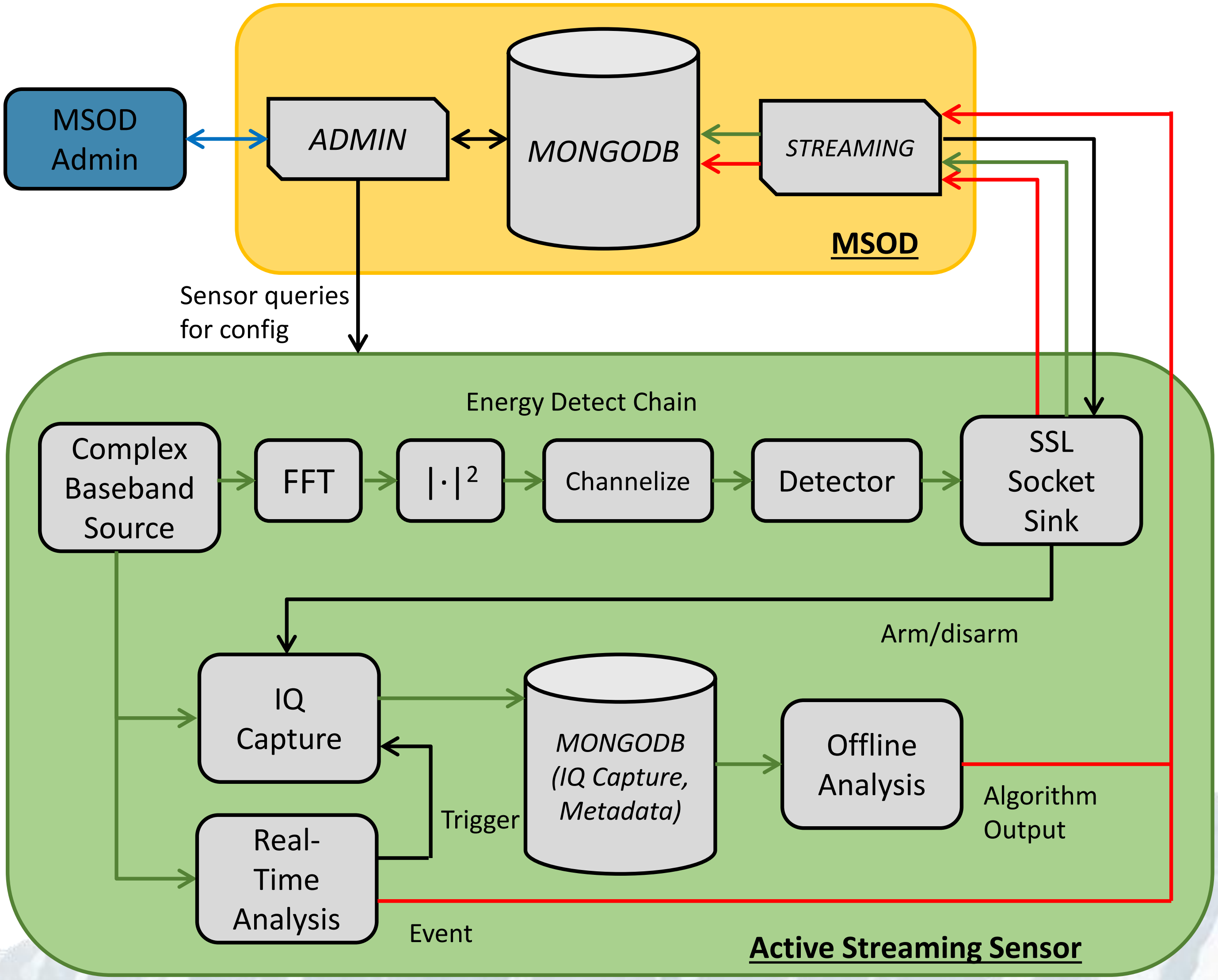
- **Every JSON message**: Version, Time stamp, Sensor ID and Key
- **Location Description**: Lat/Lon/Alt, Mobility
- **System Description**
  - Antenna: Model, Pattern, Orientation
  - Preselection: Filter, LNA, Cal source parameters, e.g., passband, max power, ENR
  - COTS sensor: Model, e.g, operational frequency range, max power
  - Cal measurement parameters and data
- **Data Description**
  - System to Detect, Data Sensitivity
  - Indication of continuous measurement start
  - Overload Indicator and system noise floor
  - Measurement parameters, e.g., Detector, sample rate, ENBW, start/stop frequency, dwell time


```
{
    "Ver": "1.0.12",
    "Type": "Loc",
    "SensorID": "101010101",
    "SensorKey": 846859034,
    "t": 987654321,
    "Mobility": "Stationary",
    "Lat": 40.0,
    "Lon": -105.26,
    "Alt": 1655,
    "TimeZone": "America/Denver"
}
```


sample Location message

- **Outreach**
  - IEEE 802.22.3
  - NSF Spectrum Observatory
  - WinnForum?

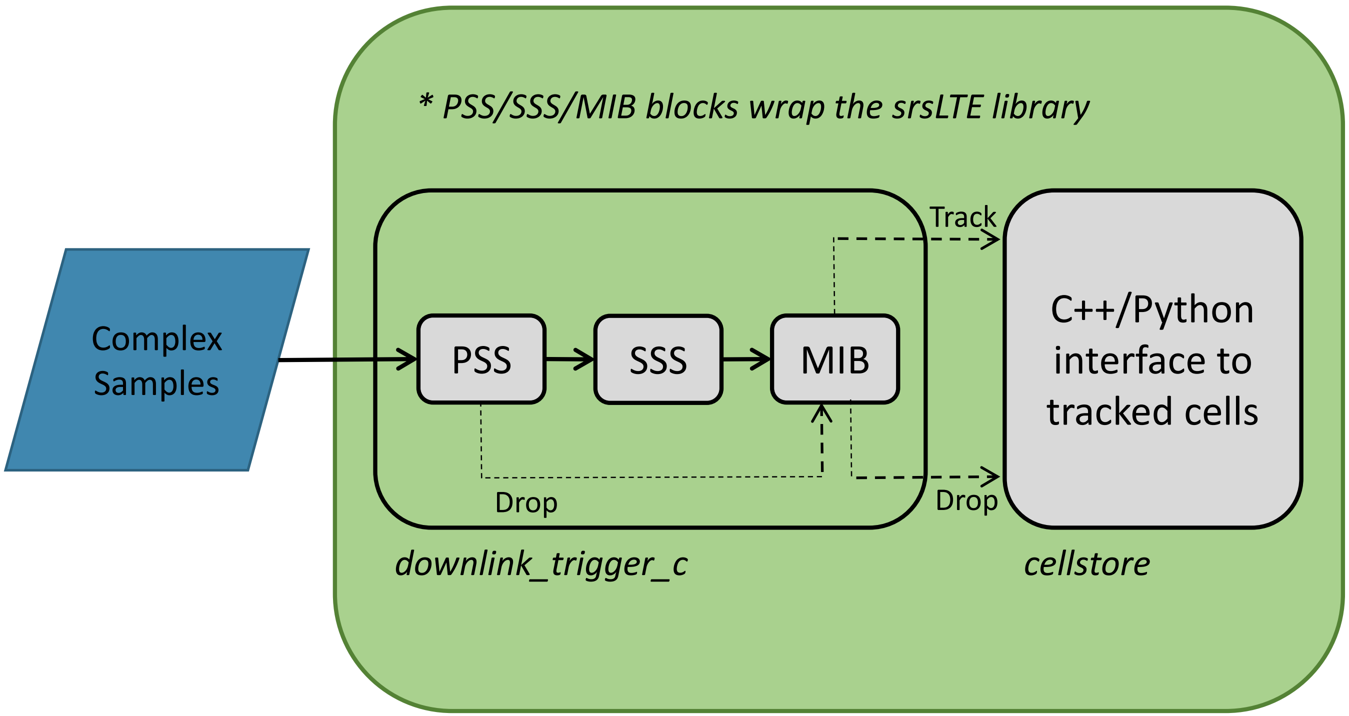
Sensor Control and Algorithmic Flexibility



- Streams/POSTs calibrated power spectra to MSOD
- Tested with multiple SDR frontends
  - USRP B200-series
  - BladeRF
  - RTL-SDR
- Swappable real-time analysis block arms I/Q capture and/or sends event message to MSOD:
  - Power threshold detector
  - LTE downlink detector
- On-sensor offline analysis of automatically or manually requested I/Q capture

Data	Control
Metadata	UI

Forensic LTE Downlink Identification (Who, What)



SDR/file source

LTETrigger GNU Radio processing blocks

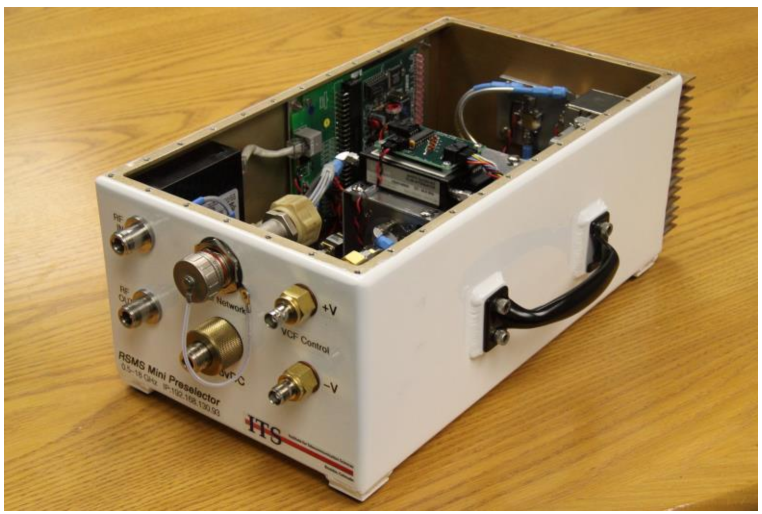

```
{
   "cell_id": 236,
   "nof_tx_ports": 2,
   "nof_phich_resources": "1",
   "nof_prb": 50,
   "phich_len": "Normal",
   "tracking_start_time":
1469123956,
   "cp_len": "Normal",
   "sfn_offset": 560
}
```


Sample output

Sensor Prototypes

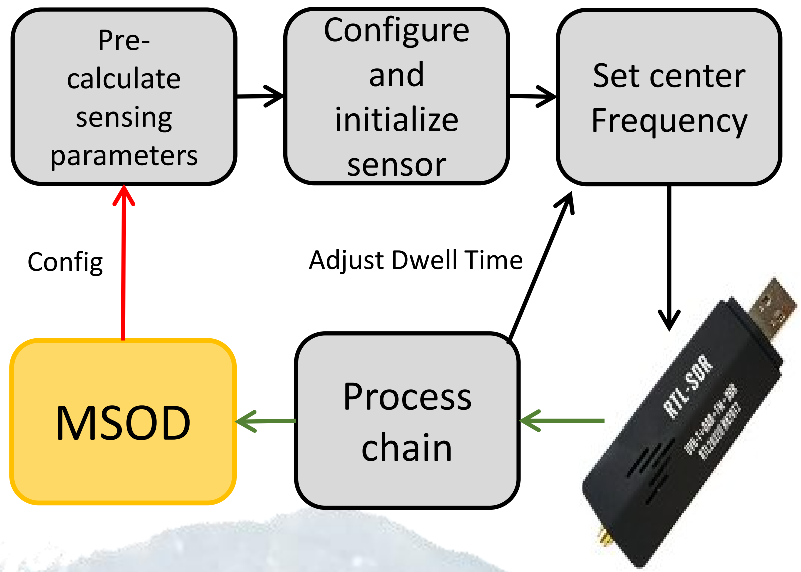
Radar Sensor (3.5 GHz ESC+):

- Preselection, local calibration, adaptable dynamic range
- Slant polarization omnidirectinal antenna
- Networked to support remote control and automatic backhaul



Citizen Science Sensor

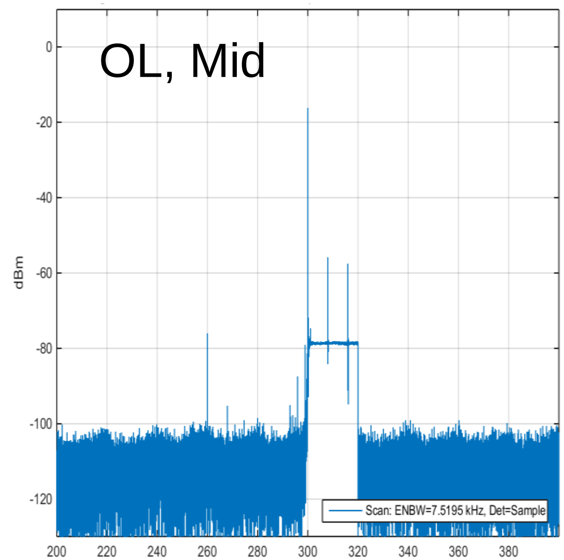
- Crowd-sourced measurement campaign
- Ultra-cheap hardware (RTL-SDR)
- Software bundled and packaged to be easy to install and configure

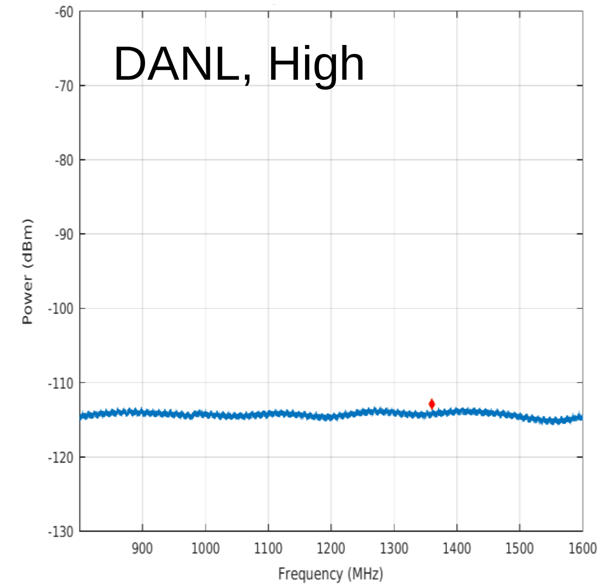


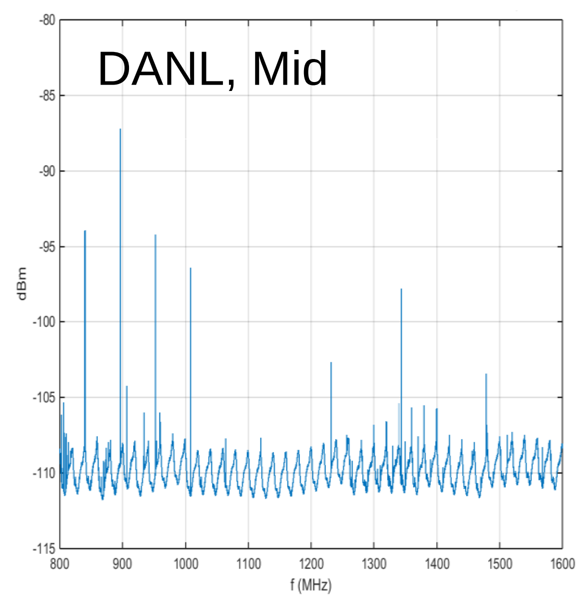
SDR Testing and Calibration

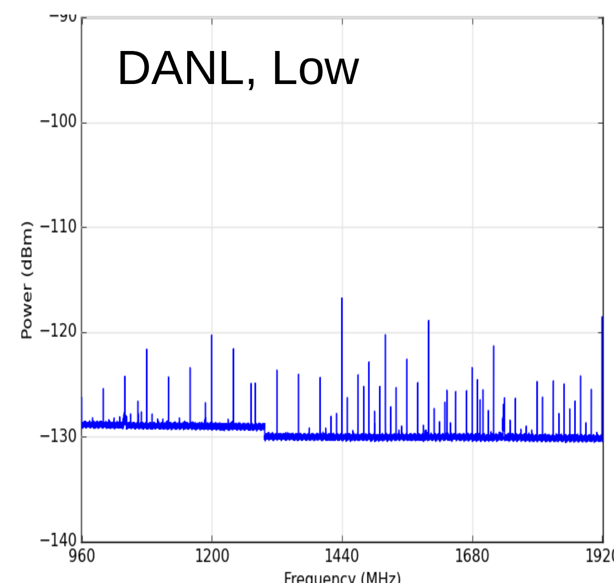
<u>RF Performance Tests</u>

- Displayed Average Noise Level (DANL)
- Self-Generated Spurious Response
- In-Band Signal Overload
- CW Signal Spurious Response
- Third-Order Intercept
- Noise Power-Ratio
- Frequency and Amplitude Stability
- Phase Noise









Next: Boulder Wireless Test Bed

Establish Boulder as a Wireless Test Bed for the purpose of research, education, and development of current and future wireless technologies.